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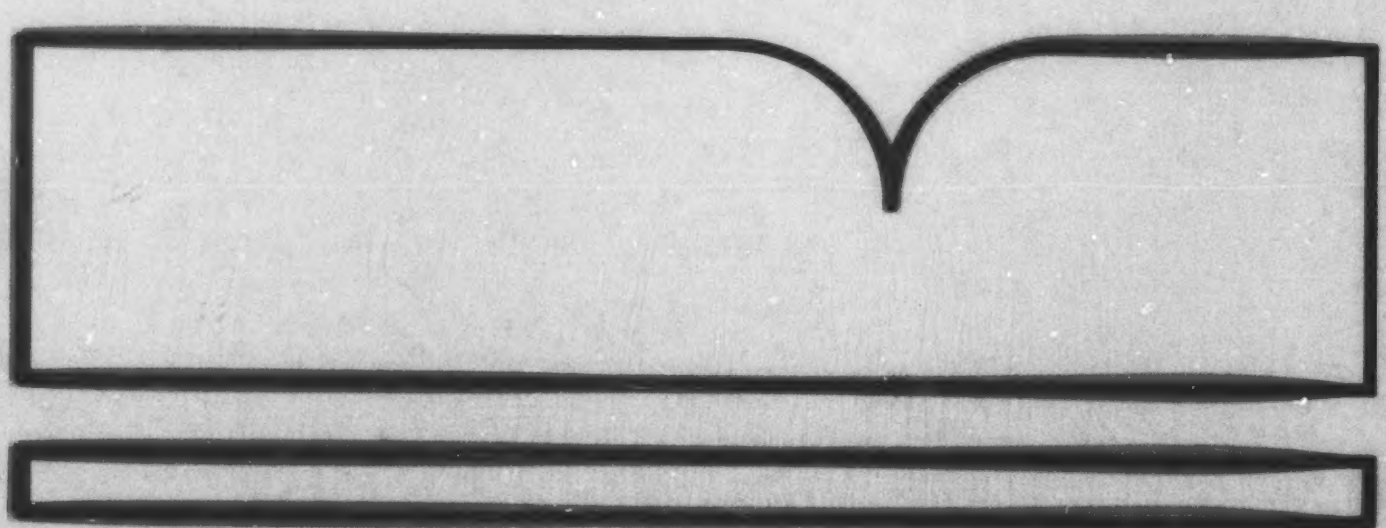

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16. ABSTRACT

The literature review of 320 references was conducted in an EPA-funded project to identify the needs for further research on activated sludge clarifier design and performance. The findings were summarized in a report and used as a basis of a 3-day research needs symposium. The prioritized research needs are presented in the paper, along with recommendations for the conduct of such research. The latter includes protocol, roles of various organizations, and minimum sizes of facilities to require to secure meaningful data.

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Activated sludge clarifiers: design requirements and research priorities

Rudy J. Tekippe, Jon H. Bender

Secondary clarifiers perform an important dual function in the activated sludge process. They must provide an overflow low in suspended solids (SS) as well as an underflow sufficiently concentrated in SS to maintain an active biomass in the aeration basin. Though clarifiers have served this purpose for decades, opinion differs as to what constitutes optimal design. Divergence of process design has been considered by many professionals to be one of the major causes of inconsistent and unacceptable effluent quality from the activated sludge process. Therefore, the U.S. Environmental Protection Agency (EPA) funded a research project to critically review the literature, interpret information, and prepare a report. In addition, EPA sponsored a symposium of leading experts in clarifier design, research, and operations to review the report, and identify and prioritize research needs in this field. The final report entitled "Critical Literature Review and Research Needed on Activated Sludge Secondary Clarifiers" was completed in September 1986. It includes literature review findings and the consensus of research priorities developed in the symposium. This paper presents an overview of the report contents.

CRITICAL LITERATURE REVIEW OBJECTIVES AND PROCEDURES

The objective of this critical literature review was to compile knowledge about: what is needed for clarifier design; what is documented and known from the literature; and what remains to be learned through further research.

The literature review included over 300 entries and provided the basis of information and discussion at the symposium in a draft report form. Comments made and references identified by the attendants at the symposium were added to produce the final report.

Numerous aspects of activated sludge clarifiers were considered in planning and prioritizing research. For example, sizing, shape, inlet details, outlet details, depth detention time, in-tank baffles, skimmers and operational strategy are all important to the unit performance. Likewise, the impact of the upstream aeration basin and its design and operation may be critical. These aspects were investigated and prioritized into the following list: sizing; shape; inlets; outlets; sludge removal mechanisms; and operations.

EPA SYMPOSIUM ON ACTIVATED SLUDGE SECONDARY CLARIFIERS

Personnel from a variety of envrionmental engineering backgrounds were selected to properly establish research priorities at a symposium. The participants, representing consulting engineering firms, regulatory agencies, equipment manufacturers, operational consultants, and universities, were given draft copies of the Critical Literature Review report and invited to the 3-day symposium starting July 15, 1986 in Cincinnati, Ohio.

The first day was devoted to group discussions of the literature review on a section-by-section basis. Two tables of five participants each were set up to encourage participation by all. The members of each of the two groups changed as the topics of discussion changed from one clarifier aspect to another. Facilitators were used to assist in stimulating the discussions.

On the second day, the entire group participated in developing a list of research questions. Prioritization criteria were then identified and a consensus reached as to which would be used to screen out the less important research questions. The initially-proposed criteria and the final ones used are identified following the research findings in this paper. Using this structured screening procedure, the original list of 56 research ideas was reduced to 32 and subsequently to a final list of 14.

The third day of the symposium was devoted to making assignments of people responsible for presenting the results to the EPA staff, preparing the presentation materials, and making the presentations.

RESULTS OF THE CRITICAL LITERATURE REVIEW

The Critical Literature Review is organized around the six aspects of clarifier design identified above. For each aspect, common design criteria and practices are greatly abbreviated or even eliminated. Such details are presented in the WPCF "Clarifier Design" Manual of Practice No. FD-8[1] and other such manuals. The references given are minimal to illustrate typical information sources. A synopsis of the final report that contains the complete bibliography of 320 entries follows.

A working group applies criteria to its collective ideas for clarifier research.

Sizing. As presented in the WPCF Manual[1] the literature contains numerous articles written to assist the engineer in clarifier sizing. Most focus on hydraulic and solids loading design values for sizing the surface area and on depth. These represent the sizing needs of a design engineer.

Two parameters used to determine surface areas for clarifier design are surface overflow rate and solids loading. The general belief is that increased surface area for a given flow, resulting in

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a lower overflow rate, produces a higher quality effluent. Mathematical equations to correlate effluent total suspended solids (TSS) with solids loading, mixed liquor suspended solids (MLSS) concentration and sludge volume loading were also found. Careful examination of these showed that effluent TSS correlates with overflow rate to varying degrees. For some equations, overflow rate is used directly with a correlation coefficient, whereas in others it is raised to the power of an exponent between 0 and 1.0.

Effluent TSS and solids overflow rate correlation is affected by tank depth as well as the flocculation-ability of the influent structure (Figure 1). It is apparent that the correlation therefore is not simple, but involves other variables. Attempts to correlate effluent quality with MLSS loading rate have likewise produced variable results.

Adequate tank depth in clarification was discussed as far back as 1904 by Hazen.[3] Camp[4] speculated that clarifiers with greater depths provided more opportunity for flocculation, but provided no data to back his claim. Anderson[5] conducted full-scale tests in Chicago in 1945 to determine the effect of activated sludge clarifier depth. He changed depths by varying the sludge blanket thickness in a circular tank with a side wall depth of 3.55 m (12 ft). Many authors present opinions and several present data supporting the contention that deeper tanks achieve better performance than shallow ones. Specifically, Parker[2] presented data showing that average effluent TSS for a number of clarifiers in western U. S. municipalities decreased from about 16 mg/L at 3.7 m (12 ft) of depth to less than 5 mg/L for 5.5 m (18 ft) of depth.

Chapman[6] performed research using a 2.4-m (7.9-ft) diameter clarifier settling activated sludge mixed liquor. He found effluent TSS to correlate positively with overflow rate at shallow depths, but no correlation or even an inverse correlation as tank depths were increased from 1.5 to 2.5 m (4.9 to 8.2 ft). These results, of course, must be interpreted in terms of the pilot scale of the equipment, but the data nevertheless suggest that tank depth has an effect on the relationship between effluent solids and hydraulic loading.

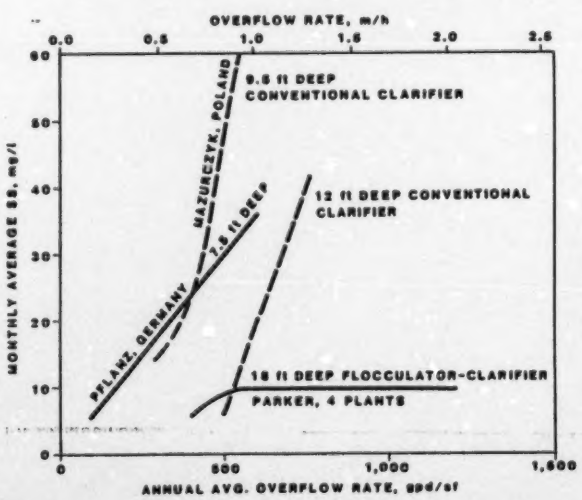

Figure 1—Performance response curves for conventional clarifiers and flocculator-clarifiers.

Shape. Although activated sludge clarifiers come in various shapes, they may be categorized by either the radial or plug flow patterns of internal liquid movement. Radial flow tanks are circular or a modification (square, hexagonal, and octagonal) of that shape. Plug flow clarifiers, on the other hand, are typically rectangular.

Design engineers need to know the relative merits of the different tank shapes. Specifically, can higher overflow rates or shallower depths be used for clarifiers of one shape versus another? In addition, engineers need to know maximum and minimum dimensions, such as diameters, to help define optimum tank numbers and orientations.

Many advantages and disadvantages for clarifiers or different shapes have been found in the literature and definite preferences exist.[7] Economics, quick sludge removal, and better mechanism reliability were the major reasons cited for these preferences.

The relative economics of rectangular and circular clarifiers were discussed by several authors. Some showed rectangular clarifiers to be more economical to construct because of their common walls between tanks; whereas others stated that common wall arrangements have drawbacks in that they are difficult to bypass and modify. Camp[8] contended that long rectangular tanks are superior to radial flow tanks because they minimize inlet and outlet effects and short circuiting. His recommendations were based on experience in laboratory data that are not presented in his papers. Although many model and full-scale tests have been performed on clarifiers, little data have been generated to effectively compare circular versus rectangular shape performance.

Inlets. Inlet design is recognized as a very important clarifier aspect. Inlets must dissipate influent energy, distribute the flow evenly in vertical and horizontal directions, reduce density current impact, minimize sludge blanket disturbance, and promote flocculation. The design engineer needs to know what type and size of inlets are required for each clarifier shape.

Inlet energy dissipation and influent flow distribution evenly in both vertical and horizontal direction is generally considered desirable by design engineer.[7] Several authors have studied hydraulic flow through clarifiers of different shapes by using tracers and have shown that poor distribution or jetting of the incoming flow results in short circuiting, as evidenced by early initial trace and peak concentration values.

Density currents from plunging mixed liquor inflow are commonly observed and considered detrimental to clarifier performance. Some inlets are designed to reduce density current impacts by feeding the mixed liquor into the lower portions of the tank or spreading the mixed liquor flow over a large area. Small deflectors to direct the inflow upward have not been successful.[9]

Another clarifier inlet function is to avoid disturbance of the sludge blanket to the point of degrading effluent quality. In full-scale, circular tank research by Crosby,[9] it was shown that inlet baffles with bottom elevations near that of the sludge blanket surface resulted in resuspension of settled solids and a deterioration of effluent quality.

Flocculation promotion by inlet design dates back decades to the time of Camp.[10] Papers by Kalbskopf and Herter[11] and Parker and Stenquist[12] for example, present such data for rectangular and center-feed circular tanks, respectively. The latter reference shows large differences in effluent SS, particularly at overflow rates above 1.0 m/h (600 gpd/sq ft).

Model and full-scale tests of several different types of rectan-

gular tank inlet diffusers or baffle plates were reported.[13,14] Devices creating impingement for energy dissipation and flocculation produced higher quality effluents and longer dye-test detention times. The combination of lowering the feed point elevation and placing the sludge drawoff point at the far end of the tank was favored by Gould,[15] but comparison data were not published.

The concept of using mechanical flocculation to improve rectangular performance was supported by the full-scale plant data of Kalbskopf and Herter.[11] Paddle mixers were tested to flocculate mixed liquor entering rectangular secondaries at the Emscher Mouth Treatment Plant, West Germany. The data (Figure 2) show that flocculation in a separate tank improves clarification as measured by transparency of the effluent and that inlet-zone flocculation further improves transparency.

Conventional, center-feed inlets, provided for most circular clarifiers, consist of single, cylindrical baffles with baffle-to-tank diameter ratios of about 10 to 15%. Recently, several researchers have tried to improve performance by enlarging the inlet zone. At Morgantown, N. C., Crosby[9] directed the installation of a mid-radius ring baffle which extends upward to about mid-depth from the floor. The resulting inlet zone enlargement reduced effluent SS from 89.1 to 52.3 mg/L.

Large diameter (35% of tank diameter) flocculating feed wells were also favored in articles by Stukenberg, *et al.*[16] and Parker.[2] Both considered mechanical agitation but found inlet energy dissipation adequate to achieve floc growth.

Several dye tracer studies, conducted 20 to 30 years ago, which used models and full-scale circular clarifiers show that peripheral-feed circular clarifiers have higher hydraulic efficiencies than conventional center-feed models.[17,18] Side-by-side full-scale tests performed in Sioux Falls, S. D., showed that in addition to better hydraulic efficiency, a peripheral-feed tank also achieved higher percent SS removal.[19] A few years ago, Crosby[9] conducted tracer studies on 43-m (150-ft) diameter peripheral-feed clarifiers installed in the East Bay MUD Wastewater Treatment Plant located at Oakland, Calif. The tanks performed well when operated over a range from 65 to 150% of the 10 mgd/tank design flow.

A novel concept of influent distribution to a circular clarifier with two rotating arms located at 90 degrees to two hydraulic sludge collector arms was presented by USSR engineers Koltsova, *et al.*[20] The moving distributor which releases mixed liquor influent near the bottom eliminates the density current problem

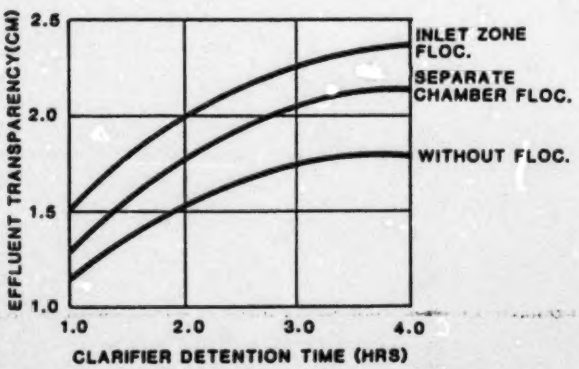

Figure 2—Improvement in the transparency of the effluent from the sedimentation stage by stirring flocculation.

of cascading inflow. The effluent is removed at the surface by withdrawal pipes with slots or orifices. The authors claim an 80 to 90% increase in tank volume efficiency based on dye concentration peak travel times. In the U. S., the Dorr-Oliver Co. has marketing rights for the concept and has been conducting full-scale tests in the Metropolitan Treatment Plant at Denver. No test data have been published at the time of this writing.

Outlets. Outlet structures for activated sludge clarifiers are intended to remove effluent from the clarifier without disturbing the sludge blanket or distorting the flow net that would then induce turbulence and impede sedimentation. Geometry choices consist of simple, peripheral weirs; cantilevered, double or multiple launders; launders suspended from the bridge; baffled, peripheral single weirs; and submerged orifices.

The basic requirements of a design engineer include the amount of weir length necessary for a given flow and the best location for such weirs (or submerged launders if they are used as a substitute).

Typical regulatory guidelines specify that weir loadings at peak flows should not exceed 124 $m^3/m \cdot d$ (10 000 gpd/ft) for plants treating less than 0.044 m^3/s (1 mgd), nor 186 $m^3/m \cdot d$ (15 000 gpd/ft) for larger plants. These values probably originate from the studies of Anderson.[5] The WPCF Manual of Practice No. 8[21] states that circular settling basins with diameters between 38 and 46 m (125 to 150 ft) perform well at weir loadings between 370 to 500 $m^3/m \cdot d$ (30 000 to 40 000 gpd/ft). It also states that tanks less than 46 m (150 ft) in diameter with double launders seem of questionable value. Although supporting data were not given by WPCF, the Manual was reviewed by 27 committee members selected for their expertise in wastewater treatment. Parker[2] recommended the use of weir loading limits of 100 to 150 $m^3/m \cdot d$ (8 000 to 12 000 gpd/ft), but did not publish supporting data.

For circular tanks, outlets may be placed at the wall (peripheral location) or cantilevered or suspended in-board. An improvement in effluent SS concentration results from decreasing the weir loading rate and moving the weirs away from the wall. The in-board location was preferred by Anderson[5] to relieve the phenomenon of solids rising along the outer wall and being caught in the outflow before resettling. Although no additional data were given, Parker[2] supports the contention that launders placed in-board about 30% of the tank radius lead to better tank performance.

Studies by Stukenberg *et al.*[16] and Crosby[9] show that the solids uplift (wall effect) can also be mitigated by a sloped or nearly flat perimeter baffle on the wall below the perimeter weir. The baffle reflects the updraft of a center-feed tank back toward the center. Crosby's sloped baffle achieved a 38% improvement in SS removal. This compares to the 42% value by Anderson[5] that uses in-board launders. For peripheral feed tanks, Boyle[22] showed that a single peripheral weir performed as well or better than an in-board, suspended launder.

Most rectangular final clarifiers used in activated sludge treatment today are constructed with weir troughs that cover approximately the final one-third of the tank. Alternatives include end weirs and submerged-orifice collectors. Although multiple launders are often necessary to meet design standard weir loading limits, Giles[23] preferred a straight baffle at the end wall for activated sludge treatment.

Sludge removal mechanisms. Settled activated sludge is typically collected and removed from the tank floor by mechanical

scrapers or hydraulic suction. These mechanisms should collect solids quickly to prevent denitrification and floating and anoxic conditions while maintaining a concentrated sludge for feed back to the aeration tank.

The needs of a design engineer attempting to select a sludge removal mechanism include relative costs, knowledge of how quickly the mechanism can remove solids from the tank, and what effect the mechanism may have on effluent quality and return sludge concentration. Relative mechanism costs are readily available from equipment suppliers and not the subject of a literature review. Long-term operation and maintenance (O&M) costs, however, depend on equipment reliability, maintenance, and repair frequency. Such data would be valuable but none have been found in publications.

The speed at which sludge can be removed from a tank is often stated as a reason to favor one design over another.[1] The need for speed has been discussed by Dick.[24] He summarizes by saying that it may very well be important to remove the sludge quickly enough to prevent denitrification (and resulting floating sludge solids) and release of phosphorous to solution; however, it may be desirable to leave the solids in the tank long enough to obtain adequate compaction of the settled sludge. Excessive detention times in some instances favor filamentous bacteria growth that subsequently may impede settling.

The original mechanisms used for activated sludge clarifiers in the U. S. included plow scrapers. Hydraulic suction was proposed in 1930 by Townsend and Brower.[25] They conducted side-by-side full-scale tests using 29-m (95-ft) diameter clarifiers at Milwaukee. Sludge blanket and percent solids depths in the return activated sludge (RAS) were measured for different RAS flow rates. The results showed that hydraulic suction could maintain shallower blankets and still remove sludge at equal or larger solids concentrations.

In 1956, Katz[26] reported that the conversion of a plow mechanism to hydraulic suction solved a problem of rising sludge solids in the tanks at Sioux Falls, S. D. Although he did not publish the data, he attributed the difference to the ability of the suction mechanism to remove solids more quickly. Soon thereafter, Katz and Gianopolis[27] studied solids retention times in 2.5-m to 4-m (8- to 13-ft) diameter circular tanks that used dye tracer to follow the solids. Hydraulic "Tow-Bro" collection mechanisms removed the sludge in residence times of approximately 20 minutes.

Mazurczyk *et al.*[28] likewise conducted sludge tracer studies of the full-scale circular tanks equipped with riser-pipe, hydraulic suction mechanisms in Pruszkow, Poland. A radioactive isotope was added to the mixed liquor and samples were collected from locations across a section of the tank and from the RAS. The sludge moved rapidly along the sludge blanket surface to the wall and then moved downward and back toward the center-feed well. It spread rather uniformly across the tank floor and after an hour, tended to concentrate in an area at about one-third of the radius from the center. The first sludge solids left the tank after about 30 minutes of settling. The peak concentration occurred after about 2 hours.

Similar studies were conducted using a 34-m (112-ft) diameter and 3.5-m (10-ft) deep center-feed tank at Czestochowa, Poland.[29] Sludge was plowed into a central RAS hopper where a relatively deep sludge blanket formed. Tracer profiles and the RAS dye concentration versus time distribution showed that much of the sludge short-circuited from the inlet directly into the central hopper.

Although many design engineers concede that hydraulic mechanisms do remove sludge from clarifiers in less detention time, some[16] contend that hydraulic suction mechanisms, in practice, often achieve less solids compaction than mechanisms with plows. If sludges are thin and deposition is uneven or both, large amounts of tank water can be collected by the hydraulic suction mechanisms.

Advantages and disadvantages of mechanical versus hydraulic sludge removal for rectangular tanks are similar to those of circular tanks. Sludge hopper location is an issue specifically investigated for rectangular tanks. Gould[15] argued against the classical approach of locating hoppers at the head end of the tank. He contended that scraping settled sludge to the influent end works against the normal density current flow and causes biological flocs to be broken and re-suspended. Gould proposed clarifiers with effluent-end or mid-length sludge hoppers. At Phoenix, Ariz., plant personnel verbally report that recent tests of parallel tanks at similar overflow rates indicate that Gould tanks are superior to conventional rectangular clarifiers. Effluent TSS concentrations below 10 mg/L were common with the Gould design.

Operation factors. Principal activated sludge clarifier operator controls include the sludge return rate, the mixed liquor TSS, and the blanket level. Common design strategy is to provide 30 to 100% RAS capacity for conventional and 30 to 150% for extended aeration plants. The design engineer needs to known how much flexibility in RAS flowrate control and aeration feed point design to provide.

Many U. S. consulting engineers[7] recommend the use of a constant, although adjustable, recyle rate as a clarifier control strategy. This allows the sludge blanket to rise and fall in accordance with diurnal and transient flows. Keinath and associates[30] introduced the "state point" concept (a means of measuring and using solids flux data) for secondary clarifier operation. The procedure involves preparing a flux curve and using it to predict clarifier response to changes in recycle and overflow rates. Optimum operating strategies can then be found.

The positive and negative effects of sludge blanket maintenance at different levels were discussed by Crosby.[9] Based on full-scale tests, he concluded that either high or low sludge blanket levels are acceptable under certain conditions; blanket depths near the bottom of the center feedwell should be avoided. For poor settling sludges leaving excessive solids in the supernate, maintenance of a high blanket may help trap some of the particles as well as compact the RAS sludge. Arguments against thick blankets center on clarifier vulnerability to solids carryover and reduced volume for settling. With well-settling sludge, Crosby recommends use of a lower blanket height. Parker[2] likewise supports the concept of very shallow blankets. Dick and Javahari[31] and Mazurczyk and Smith,[29] however, found no relationship between blanket depth and thickening, or clarification, respectively.

The concept of using aeration basin step-feed control to reduce the solids flux to the final clarifiers has been discussed in quantitative terms by Buhr, *et al.*[32] Shifting from plug flow to step feed keeps a higher fraction of a system's total sludge in the aeration basin thereby reducing the solids loading to the final clarifiers. The RAS concentration typically drops in response to such a shift.

SYMPOSIUM PRIORITIZATION RESULTS AND CONCLUSIONS

After listing research questions for each aspect of clarifier design, the symposium participants proposed eight criteria for prioritization. Each criterion was rated on a scale of 1 to 5, 5 being most important. The following list gives the criteria and the average rating given to each by the participants:

1. Improvement in effluent SS per dollar invested
   a. Research (1.7)
   b. Application (4.5)
2. Improvement of existing plants (upgrading) (3.9)
3. Improvement of reliability (process and mechanical) (3.1)
4. Status and depth of existing knowledge (3.8)
5. Feasibility of implementing the research (3.4)
6. General applicability (4.5)
7. Research marketability (1.9)
8. Institutional constraints (1.0)

The criteria were then ranked and screened to form the following list of three: cost effectiveness; status of knowledge; and applicability to new and existing plants. These were further reduced to status of existing knowledge and relative importance. A rating matrix form was prepared on this basis and used to prioritize research questions. A separate form was filled out by each participant for each clarifier aspect. The averages for each of two 5-member tables were than calculated. Research questions that did not receive high rating points were dropped from further consideration. The final list of 14 questions included the following:

- What are the rating curves based on effluent TSS versus several key significant parameters (for example, overflow rate, depth, solids loading, RAS flow and TSS, blanket depth and settling characteristics) for each of the following types of clarifiers? Circular: center feed peripheral removal; peripheral feed peripheral removal; and peripheral feed in-board removal. Rectangular: end sludge removal; center sludge removal; and front sludge removal.
- What is the frequency and occurrence of peak flows and short-term transients and how do they affect the stability of clarifiers?
- What is the rational design variability of flux curves from plant to plant?
- Are foreign clarification technologies applicable to U. S. plants?
- What are the variables that best correlate with the performance of the best clarifiers?
- What are the flow patterns in various clarifier shapes and configurations which affect the transport of solids?
- What is the relationship between inlet design and floc formation and break up?
- Can an optimally-designed flocculation structure/inlet cost-effectively upgrade an existing rectangular and circular clarifier or both?
- What are the shear characteristics of clarifier inlet structures and their effect on flocculation?
- What is the effect of aerator flocculation and break up on clarifier performance?
- How do the performances of in-board launders and peripherally-baffled weirs compare?
- How do properly designed and configured baffles affect clarifier performance?
- What is the optimum location of effluent weirs for different clarifier configurations?
- How do the sludge residence times created by different types of sludge removal mechanisms affect clarifier performance?

RECOMMENDATIONS

The literature review and symposium identified a number of basic research recommendations relating to future clarifier studies:

The profession should join to standardize on definitions. Detention time (based on overflow versus inflow), depth (side water versus average), sludge blanket surface, and blanket depth are examples of vague definitions.

Future research should be performed on full-scale tanks. Pilot-size units do not adequately simulate some variables such as eddy currents, large-scale roll patterns, wind effects, and density currents.

Future research must recognize that there are numerous and often interacting important variables that affect performance. Flow fluctuations, aeration tank turbulence, and flow splitting that occurs elsewhere in the treatment plant are examples.

Proper protocol should be established and followed for conducting additional research on clarifiers. The following points should be considered:

- Documentation of all conditions is needed. Dimensions, flows, temperatures, wind velocities, sludge volume index and SS volume index of the sludge, MLSS concentrations, for example, should be defined even though some may not be the most interesting variables in a given study.
- Proper experimental design using modern statistical techniques such as factorial and fractional-factorial designs should be followed in research planning.
- Statistical model building techniques are recommended in equation formulation to relate performance to independent variables.
- Enough data points should be measured to enable definition of statistical significance.
- Research publications should include ideas for further research to help guide others who may be pursuing parallel research.
- Research results should be subjected to peer review and published in well-recognized journals or reports (such as EPA reports), to share knowledge gained and maximize the benefits to environmental engineering design projects.

Research on clarifiers should be pursued on several fronts. The following roles are listed to illustrate some unique advantages of different parties:

- EPA and national research centers: serve as central knowledge bank and potential source of supplementary funding or knowledge of funding; and provide continuity.
- Universities: provide guidance and manpower in research planning, statistics, testing techniques, and data collection.
- Consultants: document tank performance they design and incorporate research findings into new designs so that clarifier design experiences forward evolution.
- Governmental agencies (owners): collect data from oper-

ating facilities and conduct research to optimize existing plant performance. Unbalanced load testing and tracer studies represent examples.

- Equipment manufacturers: assist in funding and conducting research efforts regarding mechanisms; and publish as much of the existing in-house data collected as possible (it is recognized tha some data may be proprietary to gain competitive advantage).

Representatives from all of the above should work more closely together to help further research needs prioritization and achieve implementation.

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REFERENCES

1. "Clarifier Design." Water Pollut. Control Fed. MOP No. FD-8, Washington, D. C. (1985).
2. Parker, D. S., "Assessment of secondary clarification design concepts." *J. Water Pollut. Control Fed.*, 55, 349 (1983).
3. Hazen, A., "On Sedimentation." *Transaction ASCE*, 53, 1904.
4. Camp, T. R., "A Study of the Rational Design of Settling Tanks." *Sew. Works J. (now JWPCF)*, 8, 742 (1936).
5. Anderson, N. E., "Design of Final Settling Tanks for Activated Sludge." *Sew. Works J. (now JWPCF)* 17, 50 (1945).
6. Chapman, D. T., "Final Settler Performance During Transient Loading." Paper presented at the 57th WPCF Annual Conference, New Orleans, La. (1984).
7. Tekippe, R. J., "Activated Sludge Circular Clarifier Design Consideration." Paper presented at the 57th WPCF Annual Conference in New Orleans, La. (1984).
8. Camp, T. R., "Sedimentation and the Design of Settling Tanks." *ASCE Transactions*. 2285, 895 (1945).
9. Crosby, R. M., "Evaluation of the Hydraulic Characteristics of Activated Sludge Secondary Clarifiers." Project Report EPA-68/03-2782, U. S. EPA, Washington, D. C. (1984).
10. Camp, T. R., "Studies of Sedimentation Basin Design." *Sew. and Ind. Wastes (now JWPCF)*, 25, 1 (1953).
11. Kalbskopf, K-H, and Herter, H., "Operational Experiences with the Sedimentation Tanks of the Mechanical and Biological Stages of the Emscher Mouth Treatment Plant." *GWF Wasser/Zbwasser*, 125, 200 (1984).
12. Parker, Denny, and Stenquist, Richard, "Flocculator-clarifier performance." *J. Water Pollut. Control Fed.*, 58, 214 (1986).
13. Mau, G. E., "A Study of Vertical-Slotted Inlet Baffles." *Sew. Ind. Wastes (now JWPCF)*, 31, 1349 (1959).
14. Rohlich, G. A., "Investigation of the Behavior of Oil-Water Mixtures in Separators." Final Report, University of Wisconsin (1951).
15. Gould, R. H., "Final Settling Tanks of Novel Design." *Water Works and Sewerage*, 90, 133 (1943).
16. Stukenberg, J. R., *et al.*, "Activated sludge clarifier design improvements." *J. Water Pollut. Control Fed.*, 55, 341 (1983).
17. Dague, R. R., "Hydraulics of Circular Settling Tanks Determined by Model-Prototype Comparison." M.S. thesis, Iowa State University, Ames (1960).
18. Katz, W. J., and Geinopolos, A., "A Comparative Study of the Hydraulic Characteristics of Two Types of Circular Solids Separation Basins." Paper presented at the Manhattan College Waste Treatment Conference, No. 7. (1957).
19. Konrad, W. N., "Studies on a Peripheral-Feed Circular Basin." Paper presented at the Florida WPCF Conference, Orlando, Fla. (1961).
20. Koltsova, S. I., *et al.*, "Methods of Improvement of Secondary Settling Tanks Operating Efficiency." *Ind. Water Eng.* 15, 24 (1978).
21. "Wastewater Treatment Plant Design." Manual of Practice 8, Water Pollut. Control Fed., Washington, D. C. (1977).
22. Boyle, Wm., "Improved Secondary Clarifier Performance: Peripheral Versus Center Effluent Arrangement." *Water Wastes Eng.*, (1976).
23. Giles, J. H. L., "Inlet and Outlet Design for Sedimentation Tanks." *Sewage Work J. (now JWPCF)* 15, 609 (1943).
24. Dick, R. I., "Folklore in the design of final settling tanks." *J. Water Pollut. Control Fed.*, 48, 633 (1976).
25. Townsend, Darwin W., "Sumary Report upon Sedimentation Tank Capacity and Sludge Concentration Tests." (1931).
26. Katz, William J., Rex-Chainbelt Corp., In-house memorandum. Milwaukee, Wisc. (April 1956).
27. Katz, W. J., and Geinopolos, A., "A Study of the Solids Retention Characteristics of a Final Clarifier in the Activated Sludge Process." Paper presented at the First International Water Pollution Conference, London, England (1962).
28. Mazurczyk, A. L., *et al.*, "Methodology for Assessing Clarifier Operation as Demonstrated at Pruszkow, Poland." Paper presented at the 53rd WPCF Annual Conference, Las Vegas, Nev. (1980).
29. Mazurczyk, A. L., and Smith, Jr., J. E., "Hydraulic Efficiency of Radial Final Settling Tank." Rep. Project JB-5-532-26, Institute of Meteorology and Water Management, Water Engineering Division, Warsaw, Poland (1983).
30. Keinath, T. M., "Operational Dynamics and Control of Secondary Clarifiers." Paper presented at the 57th WPCF Annual Conference, New Orleans, La. (1985).
31. Dick, R. I., and Javaheri, A. R., "Continuous Thickening of Non-Ideal Suspensions." PB-209 531, NTIS, Springfield, Va. (1972).
32. Buhr, H. O., *et al.*, "Making full use of step feed capability." *J. Water Pollut. Control Fed.*, 56, 325 (1984).

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